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Case Study

Case study of rutting performance of HMA modified with waste rubber powder

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ABSTRACT

Low resistance against dynamic loads and short service life of pavement are the most significant problems in the conservation and maintenance of roads, to the extent that, annually enormous costs are spent in order to improve capabilities of road services in the country. Research shows that the use of some wastes such as waste rubber powder in asphalt mixtures not only increase its serves life but also cause to reduce production costs; furthermore, recycling the crumb rubber has also considerably environmental benefits environmental benefits such as reduced need for landfill, less atmospheric pollution from burning. In this paper, the effect of adding waste rubber powder on the rutting performance of asphalt mixtures has been studied. In order to compare the performance of rubberized asphalt mixtures and conventional asphalt, wheel track test has been used. The results of this study show that the use of rubber powder caused a significant decrease in the rate of rutting depth of rubber asphalt mixtures compared to control samples.

1. Introduction

Pavement construction is one of the most important costs in the field of transportation. In a study conducted in Canada it has been found that the cost spent on the road pavement and streets, reach to 150$ million per year. Asphalt concrete is among the materials which are widely used for roads and airports pavement. About 95% of all of the world pavements is of asphalt type (Huang, 1993). These pavements over time suffer failure due to passing traffic loads and exposure to different environmental conditions. Among the most important of these failures, we can mention rutting which is considered as the main concern of transportation agencies in the field of pavement. Annually, millions of dollars have been spending to compensate rutting failures in the pavement. The temperature and stress-induced by loading can be named as two main parameters that lead to permanent deformation in asphalt pavements. When the traffic loading increases and temperatures are high, rutting failure are more likely to occurring. Research in the field of improving the constituent materials of hot mix asphalt (HMA), mix designs and methods of analysis and pavements design, including laboratory and field tests are needed to cause providing more serves life for pavements and as a result, the loss of costs which are set to be spent to repair pavement failures is prevented. Researchers and engineers are continuously trying to improve asphalt pavement performance (Huang, 1993). A conventional asphalt system consisting of asphalt concrete layers and sub-layers on the subgrade soil prepared are shown in Fig. 1 (Kok and Kuloglu, 2007).

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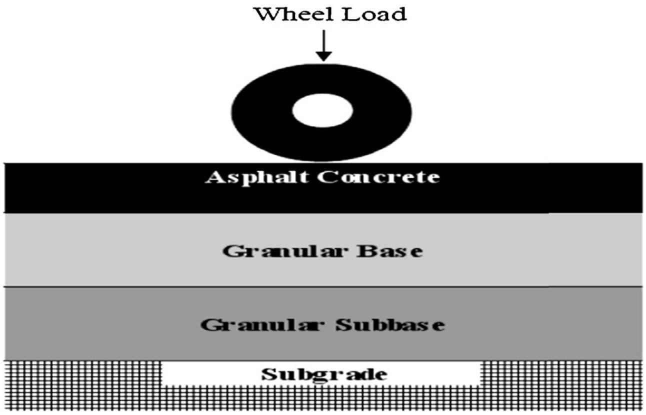

Fig. 1. Asphalt pavement system under vehicles loading.

The presence of asphalt concrete layers is the main reason to create pavement structural capacity. HMA in the pavement construction as the surface layer is used to distribute stress-induced by load and also protect unprotected sub layers from the effect of water.

Asphalt mixture for efficiently performing both of these tasks during the life of pavement design, should be resistant against the effects of climate and resist against the permanent deformation and cracking caused by load and environmental factors. Constituent material properties play a significant role in pavement construction specifications (Haghi et al., 2005).

Failures that occur during the useful life of the pavement, mainly includes permanent deformations in the path of vehicles wheel (rutting), fatigue cracking and thermal cracking. Since, enormous costs should be spent to repair and reconstruction of shortcomings and defects, so early prevention often is more economical. To avoid this failure, pavement materials should be selected so that they would have sufficient strength and stability. Aggregates must be broken, and applying excessive bitumen and fine aggregate should be avoided (Tabatabaei, 2005).

Wheel track groove (rutting) is the permanent deformation of pavement layers that can be increased over time. Pictures of wheel track groove are shown in Fig. 2. Generally, three factors led to create rutting in the asphalt pavement include permanent deformation accumulation in the surface of asphalt layer, permanent deformation of the subgrade, and erosion or wear of asphalt at the wheels place due to the passing of vehicles. In the past it was believed that deformation of the subgrade is the main reason of occurring grooves in the pavement and many of the design methods were built based on limiting the vertical strain. However, research in recent years has indicated that the main reason of rutting is related to the upper part of asphalt surface layer or surface layer (Rabbira, 2002).

Surface rutting of wheel path can cause to jeopardize road safety. Consequently, excessive rutting which is usually considered as the main cause of premature failure and repairing operations and maintenance of road network, will lead to the reduction in pavement serves life (Brock et al., 2003).

The evaluation of asphalt concrete mixtures to protect them against rutting phenomenon of wheel track has turned to the important research area in recent years. This type of failure occurs as a result of the consolidation and compaction of asphalt mixture after manufacturing and the plastic deformation caused by wheel passing vehicles over time. In recent years in order to enhance pavement flexibility as well as their resistance against destructive factors such as fatigue, cracks induced by extreme changes in temperature and permanent deformation of asphalt pavement, the utilization of waste materials that

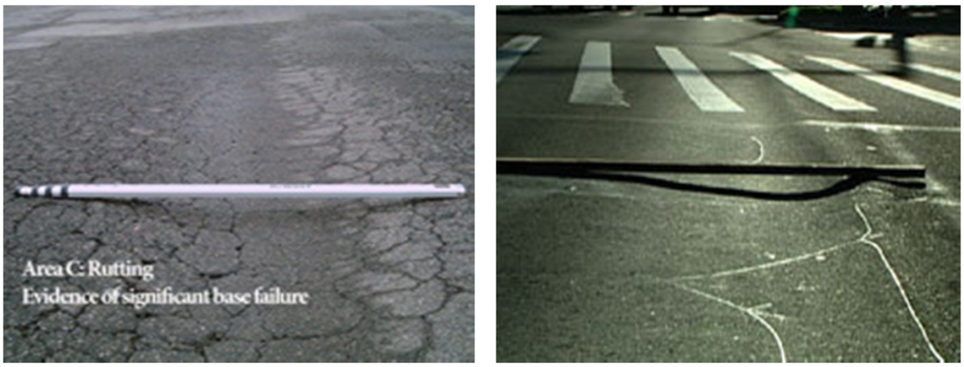

Fig. 2. Rutting phenomenon occurrence in asphalt pavement.

have the potential to improve the mechanical properties of the asphalt pavement, has been common in the construction of HMA (Kandhal, 1992). Improvement of the pavement properties is possible by applying two methods:

- Improve properties by using the modified bitumen
- Improve properties by using the modified asphalt mixtures

In recent years, ascending trend of costs of repairing and reconstruction of roads and airports pavements which is creating due to the increasing the amount and repetition of traffic loads on the pavements, has caused that a comprehensive research is conducted on the use of additives in manufacturing of asphalt mixtures to enhance their capabilities against dynamic loads. Low resistance of pavement against dynamic loads and their short life of serves are the most significant existing problems in the field of conservation and maintenance of roads.

2. Literature review

Using recyclable materials in road construction is one of the cases that its related industries have obtained extensive experience about the use of by-products in asphalt. Examples of wastes that have been used in asphalt mixtures, including glass baking furnace dross, ash obtained the incineration of municipal waste, crushed brick, plastic, rubber obtained from waste tires, waste glass and waste rubber powder. However, successful use of these products is depending on a full investigation of the sources and their characteristics and usually is done at a low level.

According to the available reports, annually, about one billion, equivalent 9 million tons waste tires are produced in the world. Due to the shortage of landfill space and environmental issues, recycling old tires seem necessary.

The value is 290 million rings in the U.S. and 110 in Japan. Collecting and storing these tires not only create pollution but also contain high costs and in addition, there is the possibility of fire in the location as well. In Iran, the annual rate of worn tires is nearly 7 million rings, approximately 220 thousand tons. On the other hand for a single truck tire, about 22 gallons of oil is used. In the U.S. and Canada, only 30% of waste tires is transferred to the sanitary centers of landfill and the rest are abandoned in the nature that make a suitable habitat for vermin and rodent such as rat and a suitable place for the growth of mosquitoes and the spread of the agent of types of diseases such as viruses. Fig. 3 shows the accumulation of waste tires in landfill. Given that the tire pieces are slowly decomposed, finding a solution for their use and reducing the environmental risks caused by their burial in the environment is essential (Bidaki et al., 2012).

The utilization of waste crumb rubber as a modifier material in the asphalt has been considerable for researchers over the recent four decades. Carried out researches in the manufacture of rubber asphalt pavement indicate the reduction of

Fig. 3. A landfill for accumulation of waste rubber.

pavement thickness, increase of pavement life, becoming less light refraction reflection rate, becoming less traffic noise, the reduction of maintenance costs, reduction of pollution and improve environmental issues.

In 2007, Wang et al. study on the effect of crumb rubber modifier on the sensitivity of high temperature of the surface mixture. In this paper, they evaluated the effect of different sizes of crumb rubber on high temperature sensitivity of three type of surface mixture. The evaluation was conducted in two parts: first, the properties of the modified and unmodified bitumen in a wide range of test temperatures and aging conditions have been compared. Then rutting resistance of modified mixtures is compared with conventional. The results of this research showed that the bitumen modified with crumb rubber have better performance to resist against rutting (Wong and Wong, 2007).

Tortum and colleagues in 2005 used the results of Marshall Test to determine the optimal conditions for the use of tire rubber in Asphalt Concrete. They considered granulated crumb rubber, fusion temperature, aggregate gradation, the amount of crumb rubber, density temperature, the amount of bitumen and fusion time as experimental variables. In this study, the method of dry mixing crumb rubber in asphalt concrete was used. The results of this research showed that rubber asphalt mixtures have more favorable Marshall's resistance than conventional mixtures (Tortum et al., 2005).

In another study, Celik and Atis (2008), studied on the phenomenon of compressibility of HMA made with bitumen modified with crumb rubber. In this paper they tried to find a link between performance and compressibility of asphalt mixtures. They used gyrating testing machine (GTM) in order to determine the performance of asphalt mixtures. The results of this study indicated that gyrating compactor can be used for evaluating the performance and compressibility of HMA (Celik and Atis, 2008).

According to the above research, necessity of conducting more complete and comprehensive investigation regarding the utilization of waste rubber powder to improve the behavioral performance of asphalt mixtures is felt. This study examines the rutting phenomenon in rubberized asphalt mixtures by wheel track test.

3. Research methodology

3.1. Materials

Used materials in the experiments consist of aggregates, waste rubber powder and pure bitumen. Aggregates gradation is mediocrity continuous gradation of HMA related to the stratum of Topeka (type 4) in accordance with Iranian standard, publication No. 101 of technical and public specifications of roads. The sizes of this grading are presented in Table 1. Bitumen used is the bitumen 70-60 of Isfahan refinery which its characteristics have listed in Table 2. Moreover, the tire crumb rubber used in this study was prepared from Yazd Tire Company. Granulated crumb rubber used is shown in Table 3.

3.2. Marshall test

This method of testing has been inserted in Standard No. ASTM-D1559, entitled "Standard Testing Method for determination of asphalt mixtures resistance against plastic deformation with Marshall Method". Manufacturing and preparing methods of specimens of asphalt mixture for asphalt mix design is performed based on Standard Method (ASTM-D1559). In this method, the cylindrical compacted asphalt mixture specimens with a height of about 63.5 and diameter of 101.6 mm are provided. Compaction action is performed by a metal hammer having a circular cross-sectional surface (diameter 98.4 mm) and weigh of 4.5 kg that freely falls from the clear height of 45 cm.

Table 1
Continuous gradation of HMA related to the stratum of Topeka (type 4).

0.075 mm	0.3 mm	2.36 mm	4.75 mm	12.5 mm	19 mm	Sieve size
2–10	5–21	28–58	44–74	90–100	100	Regulation range
6	13	43	59	95	100	Used weight percentage

Table 2
Characteristics of bitumen used in this study.

Degree of purity (%)	The weight loss (%)	Degree of combustion (°C)	Plasticity (cm)	Softening point (°C)	Penetration degree 10 mm	Density in 25 °C
99	0.75	262	112	51	66	1.02

Table 3
Crumb rubber gradation used in this study.

0.075 mm	0.3 mm	0.6 mm	1.18 mm	2 mm	Sieve size
2.5	22.5	60	82.5	100	% passing the sieves

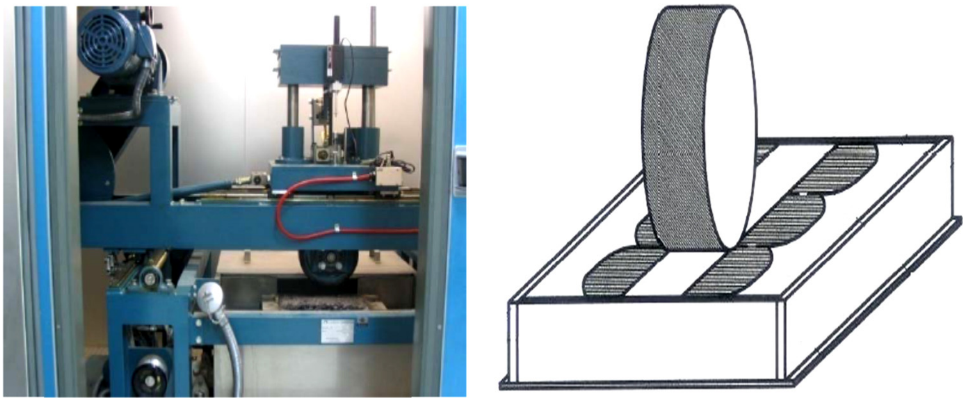

Fig. 4. Schematic view of the wheel track test and wheel track test apparatus.

According to previous studies, the optimal percentage of the utilization of waste rubber powder as a modifier of bitumen, 10% of bitumen weight has been determined; therefore, in this study, waste rubber powder has replaced 10% of the bitumen used. To mix bitumen and crumb rubber, the mixer equipped with a thermocouple and thermostat is used until fusion occurs at the desired temperature. Mixing is done with a speed of 1200 rpm.

In order to conducting the Marshal Test on the specimens, first the specimens are placed in a warm water bath for 30 min at 60 °C and after this period, the specimens are withdrawn from the bath and their outer surface dries. Jaws of the Marshall Apparatus lubricated and then the specimens are placed in the Marshall apparatus. With turning on the machine, loading on specimens is performed.

According to the Marshall Test results, in the conventional asphalt specimens, optimum percentage of bitumen is 6%. Moreover, according to the Marshall Test results, optimal amount of bitumen modified with rubber powder for rubberized asphalt specimens, with optimum percentage of additive 5/5 percent is obtained.

3.3. Wheel track test

Wheel track rutting Test is applied to determine the resistance of asphalt mixtures against permanent deformation at critical temperatures and under loading similar to what the pavement surface is applied. This test can be done on the cylindrical kernels taken from the asphalt road as well as asphalt slab made in the laboratory. Wheel track rutting test with the reciprocating motion of loaded wheel on asphalt specimens determine the potential of asphalt pavement rutting. This is done by measuring the rut depth created in the sample along the moving of apparatus's wheel at specified intervals by rut-gauge. Desired rut-gauges should have sufficient accuracy at least 0.1 mm. The maximum rut depth measured by wheel track apparatus is 20 mm and then the machine turns off. This test is carried out according to the Standard instructions of Great Britain BS 598: Part 110 (British Standards Institution, 1996).

Acceptable segment dimensions for the construction of asphalt samples are 300 mm × 300 mm which is its most common state. Also, acceptable thickness for specimens made in the laboratory is 75 mm × 50 mm. While, for samples which are made of existing pavement, these dimensions are 35 mm × 110 mm. In this study, specimens with dimensions 300 mm × 300 mm × 50 mm were used. Given the dimensions of the mold in which slab is built (300 mm × 300 mm × 50 mm) and also the specific gravity of asphalt specimens (G_{mb}) which is calculated in the Marshall test, weight of materials required for the manufacture of asphalt slab is calculated. To perform the test, the sample should be placed into the wheel track machine and after performing the necessary setting through existing software on the computer attached to the machine, start the test. According to the Standard, the load applied to the specimen through apparatus's wheel should be 710 N but this amount can be changed. Temperatures at which these tests can be measured are in the range of 30–70 °C. Schematic view of the manner of implementing wheel track test and wheel track test apparatus is shown In Fig. 4. In this study, in order to evaluate the effect of temperature and stress on the asphalt mixtures and assess the impact of the utilization of rubber powder on improving the behavior of these mixtures in different loading conditions, wheel track test is conducted at temperatures of 40, 50 and 60 °C and applied load is equivalent to 100 and 200 kPa.

4. Wheel track test results

Wheel track test results are shown in Tables 4 and 5. As can be seen from the results, rut depth measured in samples modified with rubber powder is to a large extent lower than the amount of rut depth in the conventional asphalt specimens. This theorem is the proof of the claim of the high power of crumb rubber in reducing permanent deformation of asphalt mixtures.

Table 4
The results of wheel track tests on the rubberized asphalt samples.

Temperature (°C)	Applied pressure (kPa)	Rut depth (mm) Number of wheel passes		
		250	500	750
40	100	0.116	0.133	0.160
	200	0.263	0.296	0.365
50	100	0.357	0.414	0.541
	200	0.516	0.631	0.774
60	100	0.530	0.730	1.010
	200	0.880	1.150	1.410

Table 5
The results of wheel track tests on the conventional asphalt samples.

Temperature (°C)	Applied pressure (kPa)	Rut depth (mm) Number of wheel passes		
		250	500	750
40	100	0.146	0.180	0.219
	200	0.346	0.487	0.514
50	100	0.725	0.905	1.240
	200	0.834	0.940	1.512
60	100	1.240	1.550	1.620
	200	1.450	2.020	2.430

Figs. 5–7 show the results of rut-depth for different temperatures and stresses applied. In these figures, C represents unmodified and R crumb rubber modified and 200/100 kPa applied pressure. As was expected, increasing the stress level, rut depth in asphalt mixtures is increased but the important matter is the manner of increasing as in rubber asphalt mixtures due to the high impact of rubber powder on improving the behavior of asphalt mixtures, the rate of increase is less than control mixtures. The important point is occurred at 50 °C, so that rut depth in rubber asphalt mixture in applied stress of 200 kPa is less than rut depth in control asphalt mixture in applied stress of 100 kPa. A very important point is this that rutting phenomenon mostly occurs at high temperatures; therefore, using waste rubber powder, the amount of permanent deformation in the asphalt mixtures could be greatly reduced. This effect can be due to the improving the behavior of bitumen modified with rubber powder than conventional asphalt. Adding crumb rubbers to the bitumen cause increase its stiffness and viscosity. Improving both of these features in bitumen can lead to increase the stiffness of asphalt mixtures and the rate of rut depth in them is considerably reduced. Figs. 5–7 also illustrate the effect of temperature on the behavior of asphalt mixes. The results show that with increasing temperature, the values of rut depth either in modified specimens or in

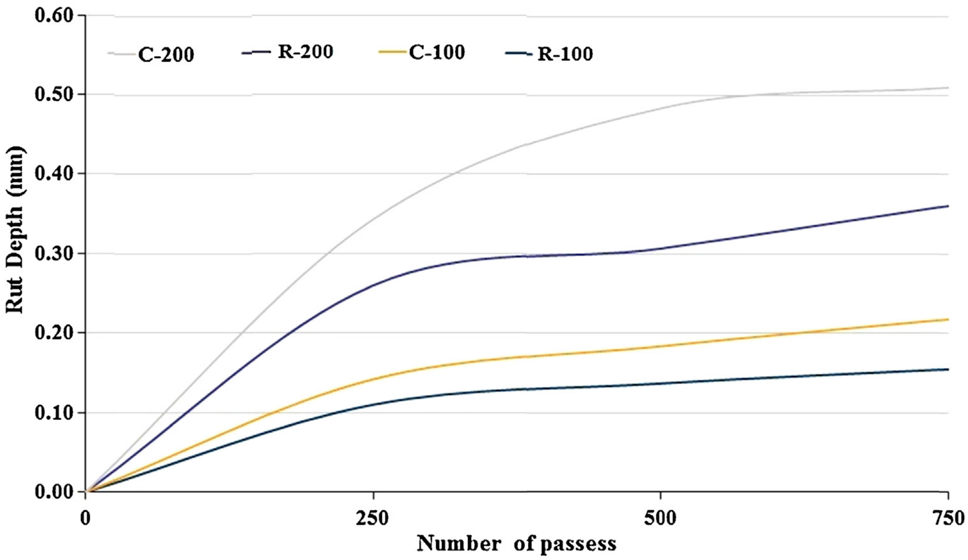

Fig. 5. Results of wheel track test for asphalt specimens at 40 °C.

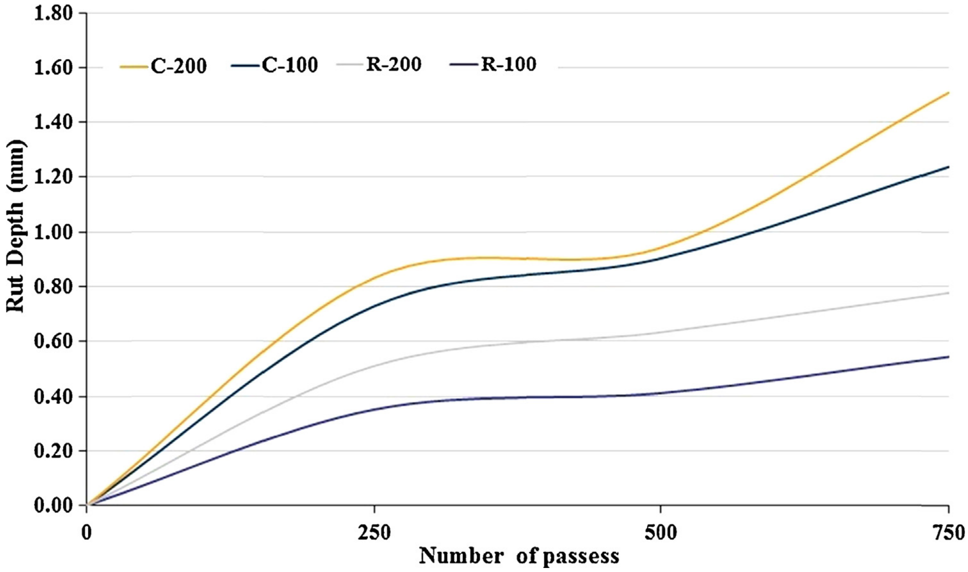

Fig. 6. Results of wheel track test for asphalt specimens at 50 °C.

conventional is increased, but the rut depth growth with increasing temperature in the rubberized asphalt samples is less. This phenomenon occurs due to the reducing thermal sensitivity of asphalt mixtures affected by the addition of crumb rubber. Softening point of bitumen is greatly improved by the addition of crumb rubber that this factor can lead to the reduction of thermal sensitivity of modified bitumen and thus asphalt rubber mixtures.

The important point in Fig. 6 is that rut-depth of control specimens in the stress of 100 kPa is greater than mastic asphalt mixtures even in the stress of 200 kPa. This result suggests that by replacing 10% of the bitumen used in asphalt mixes with waste rubber powder in addition to reducing production costs of asphalt mixtures, rubberized asphalt mixtures at high temperatures and stresses will have better performance compared to the control specimens.

The results at 50 °C show that for conventional asphalt, persistent strain rate is rapidly increasing while specimens modified with rubber powder have normal slope and thus the rut-depth is less than conventional asphalt mixtures.

Fig. 8 illustrates the effect of waste rubber powder on rut depth of samples in different stresses 100 and 200 kPa and temperatures 40, 50 and 60 °C at 750 passes of wheel. In these figures, C represents unmodified and R crumb rubber modified and 200/100 kPa applied pressure. Results show that temperature has large effect on rut depth of conventional and modified samples. For example, in conventional sample and by applying stress 200 kPa, rut depth in 50 °C is approximately 3 times

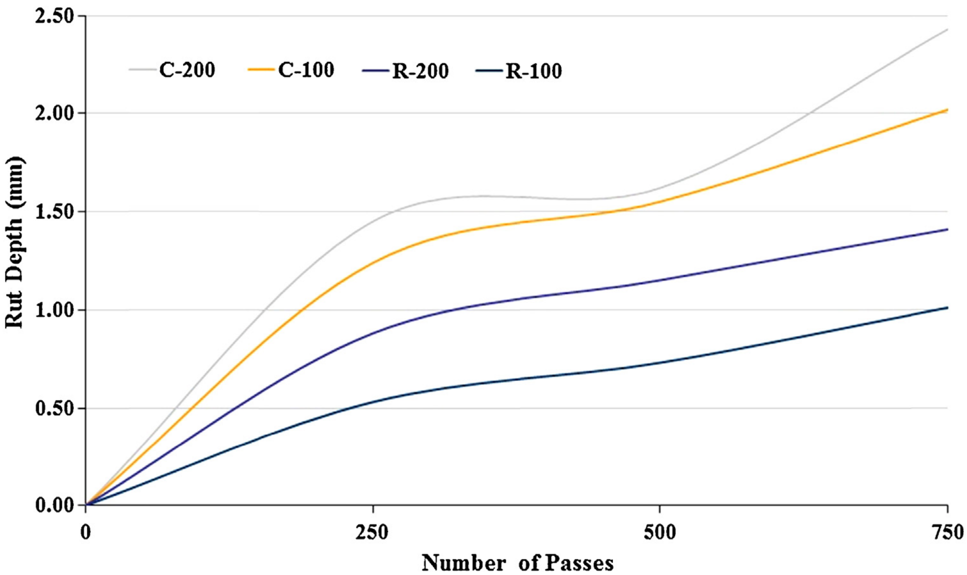

Fig. 7. Results of wheel track test for asphalt specimens at 60 °C.

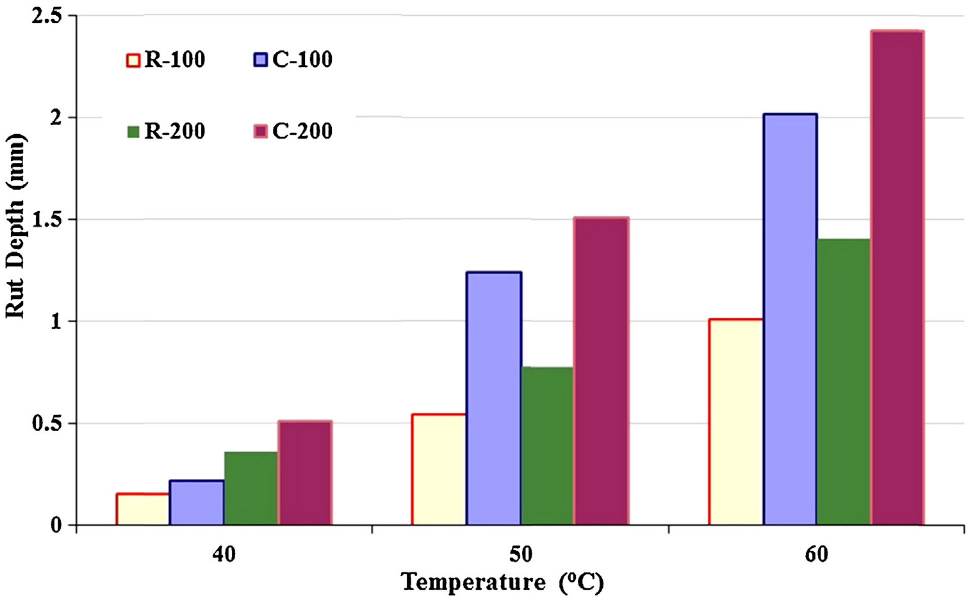

Fig. 8. Rut depth of asphalt samples at different stresses and temperatures at 750 passes.

larger in comparison with 40 °C. This shows high sensitivity of asphalt samples to temperature. In conclusion, by adding waste rubber powder to specimens, rut depth of asphalt samples is reduced significantly.

5. Conclusion

In this research, the effect of waste rubber powder on the improvement of asphalt mixtures performance and reduce rut depth caused by wheels passing by wheel track test has been examined. This experiment is carried out at two different temperatures and stresses to conduct examinations in different situations. The main results of this research are:

- Waste rubber powder has high impact on reducing rut depth of asphalt mixtures at different temperatures and stresses.
- Asphalt mixtures containing 10% waste rubber powder has better performance at higher temperatures. Rubber powder with reducing thermal sensitivity of asphalt mixtures can increase its resistance against permanent deformation.
- The results show that by replacing 10% of the bitumen used in asphalt mixes with waste rubber powder in addition to reducing production costs of asphalt mixtures, rubberized asphalt mixtures at high temperatures and stresses will have better performance compared to the control specimens.
- The results at 50 °C show that for conventional asphalt, persistent strain rate is rapidly increasing while specimens modified with rubber powder have normal slope.

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